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SELECTED APPLICATIONS OF SKYLAB HIGH-RESOLUTION
PHOTOGRAPHY TO URBAN AREA LAND USE ANALYSIS

by

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August 15, 1974

Interim Report Under Skylab/EREP
Investigation No. 469
NASA Order No. T-5290-B

(E74-10757) SELECTED APPLICATIONS OF SKYLAB HIGH-RESOLUTION PHOTOGRAPHY TO URBAN AREA LAND USE ANALYSIS Interim Report (Geological Survey, Reston, Va.) 39 p HC $5.00 CSCL 14E G3/13

N74-33825
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ABSTRACT

In research aimed at determining and demonstrating the use of the Skylab S-190B Earth Terrain Camera to detect land use patterns, changes, and associated environmental impact and to compare the S-190B with other remote sensing data sources, the land use of portions of Fairfax County, Virginia was mapped using data from Skylab, ERTS and high-altitude photography. A Skylab Level III land use map of Fairfax City was compared to a field surveyed ("Ground Truthed") high-altitude photography derived map. An accuracy level of 83 percent was calculated for the Skylab map with 42 percent of the error attributed to the misclassification of unimproved open space resulting from limitations in film spectral resolution and camera spatial resolution. In the same comparison, 130 hectares of wooded residential land were found to be misclassified as forest on the Skylab map. In a Level I comparison of ERTS and Skylab derived land use maps to high-altitude photographic data, the accuracy of the Skylab data was found to be 88 percent, with the error evenly distributed among urban, agriculture, and forest categories. The ERTS interpretation was found to have only a 65 percent accuracy. In addition, an analysis of the ground dimensions of identifiable features diagnostic of particular land use types was conducted and the results are presented.

INTRODUCTION

The U.S. Geological Survey (USGS) Geographic Applications Program is conducting a research project entitled "Urban and Regional Land Use Analysis: CARETS and Census Cities Experiment Package" to evaluate data products from NASA's Skylab earth resources program. The thrust of the USGS project is to determine and demonstrate uses of the Skylab data to enhance and improve our knowledge of land use patterns, changes, and the associated environmental impact. The present report was written as an interim product under that study, in response to a special request from NASA for information, prior to completion of the overall study, that could be used for an urgent NASA assessment of the benefits for urban area applications obtainable from higher-resolution sensors in space, in this case specifically the S-190B Earth Terrain Camera (ETC) which was used in the Skylab earth resources experiments. Presumably results of this study would be considered for relevance to decisions on future earth resources satellite systems.

The USGS team was able to respond to this short-deadline request from NASA because of the existence of a sustained program effort over the past several years motivated and directed towards objectives similar to those of the NASA assessment, and because of the impetus of the ongoing Skylab investigation (Skylab/EREP Investigation No. 469) to which the additional study could be added. The authors wish to acknowledge the advice and assistance of other USGS team members who assisted in the work reported on here, specifically Katherine Fitzpatrick, Kenneth Ferguson, Dan Gallagher, Herbert K. McGinty, Valerie Milazzo, and James Wray. Guidance and funding support from the Skylab project office at the NASA Johnson Space Center are also gratefully acknowledged, with special thanks to Rigdon Joosten, scientific monitor of the USGS project.

SCOPE OF STUDY

Owing to limitations in both time and resources, it was decided at the outset that the study would be limited to the areas imaged on two ETC photographs, one of the Washington, D.C. area (Mission 3, 5 August 1973, Frame 83-165) and the other of the Phoenix area (Mission 3, 6 September 1973, Frame 86-011). Actually the Washington, D.C. area photo was analyzed more intensively than the Phoenix area photo, owing to nearness for field checking to the USGS office in Reston, Virginia, and to the experience and familiarity of the team members who were assigned to this special study.

further limitation was imposed by restricting the scope of the analysis to just one type of urban area application of the many possible ones that might be investigated with this photography. The application selected for this special study was that of urban area land use mapping or land use inventorying, and the approach to this topic was through a multi-level hierarchical land use classification system devised specifically for use with remote sensor data (Anderson, Hardy, and Roach, 1972). See Table 1. Thus other possible uses of the ETC data for urban area analysis, such as air pollution detection and monitoring, assessing the vigor of urban vegetation, water pollution studies, recreation area analysis, and hazard or disaster surveillance, were not included in this study. Since there are obviously some potential benefits in urban area analysis applied to these other topics, the results of the present study are conservative, with respect to the capabilities of a sensor such as the ETC carried at Skylab orbital altitudes.

Given the focus of the special study on the applications of the ETC to land use inventory and mapping, the problem was to evaluate the data insofar as possible in such a way that valid comparisons with other data sources could be determined, and that the results be quantitative to the extent that they could be related to costs, benefits, and engineering parameters of future orbital sensor systems. Since there is no standard or widely accepted method of expressing the information on a land use map in quantitative terms, or of measuring the information content of remote sensor data used as input into a land use mapping process, a variety of separate methods of evaluation was employed, as explained in detail in the section on "Analysis Methodology". Thus, the body of the study consists of these micro-evaluations of selected areas which are only a small percentage of the total area covered by the frames examined. Even with these restrictions, plus the above-mentioned limitations in the scope of the study, it is believed that the results have sufficient generality to merit extrapolation to other areas, regional and environmental differences notwithstanding. This is believed possible because of the similarity, in both ground dimensions and morphology, of the structural elements that together make up present-day American urban complexes as they are viewed from above.

METHODOLOGY EMPLOYED IN ANALYSIS

Image Analysis and Approaches to Quantification

The assignment of a particular land use category to each portion of the Skylab photography selected for analysis was done by a process of manual photointerpretation, which, because of the high quality of the photos, was readily accomplished after a minimum time spent in becoming familiar with the appearance of different types of land

use as depicted. A summary of data sources is given in Table 2. The familiarization process was enhanced by the use of U-2 underflight photography, along with selected field checking. In an automobile traverse in the field it was found, for example, that it was possible to locate oneself directly on a seven-times enlargement of the ETC photograph. Prior knowledge of the regions under study was employed to a certain extent by the investigators; this situation is considered to be realistic in terms of actual use of the data by planning agencies.

The starting point for the land use analysis performed in this study was the two-level classification system already referred to (Anderson, et al., 1972). That classification system has been widely reviewed since original publication, and a proposed modification is being circulated for further review at this writing. The categories and definitions used in the proposed modification are the ones employed here, with the addition of third-level categories where applicable to the analysis of the ETC data.

Using the appropriate levels of this three-level classification system to derive a variety of data sets and descriptions from the Skylab photography, measures and comparisons were developed along four independent approaches: (1) systematic aligned sample; (2) area measurement comparison of classification elements; (3) determination of the ground dimensions of the identifiable feature diagnostic of a particular land use type, and (4) visual assessment (this being more qualitative in nature). ERTS and high-altitude aircraft data were used for comparison. Each method was employed in different circumstances as detailed in the sections following.

Explanation of Methods

The first, and most comprehensive, quantification technique used in this study was a comparison of maps derived from different remote sensor data, the comparison based on a grid or systematic aligned sample of points drawn from the different maps. This method simply compares two spatial data sets by a corresponding point sample drawn from each (Berry and Baker, 1968). For example, suppose we have two polygon maps A and B which cover exactly the same geographical area and use the same units of classification. Map A resulted from the interpretation of sensor X data and Map B from analysis of sensor Y data. By observing points on one and then the corresponding points on the other we can determine which points, if any, have classification differences. If we further assume that Map A, because of certain characteristics in sensor X combined with more detailed information from additional sources (e.g. other maps, etc.), is "ground truth" then providing the two maps are temporally similar any points on Map B, different from those on Map A, can be considered misinterpretations. If we divide the number of points found to be different by the total number of points examined the quotient will be a fraction which can be considered to be a measure of comparability or accuracy.

Since the mapped data appeared not to contain any regular repeated pattern or spatial periodicity, a grid or systematic aligned sample was employed. The geographical areas to be analyzed were overlain by a grid of equal-sized cells and the center point of each cell served as the observation point. The cell size is arbitrarily determined based on the amount of reliability desired and the scale of the data. Obviously many small cells make for a much more accurate account than several large cells. In the Fairfax City example 69 sample points were examined (map scale 1:24,000) and in the portion of Fairfax County example 225 sample points were checked (map scale 1:125,000).

A second quantification technique employed was the comparison of area measurements of land use types. Consider a classification system consisting of n units. For any given map using this classification the sum of the areas of each classification unit used will equal 100 percent of the total area of the map. Now let us further consider the case where we wish to examine three maps E, F, and G of the same geographical area which were produced using the same classification system. Map E was generated from source R, Map F from source S, and Map G from source T. If we let Map E, because of superior source information, be considered ground truth, then by comparing the percentage of area of each classification unit in Maps F and G to the percentage of their corresponding areas in Map E we can determine how accurate by each classification unit Maps F and G are. Suppose we employed a classification with units 1, 2 and 3 and our ground truth map had 20 percent of its area in unit 1, 30 percent in unit 2, and 50 percent in unit 3. Then we examined another map with constituents of 21 percent in 1, 31 percent in 2 and 48 percent in 3. By observation it is easy to deduce that the two are very similar. If on the other hand there were sizable discrepancies in the percentages then a comprehensive look into the reasons for such differences would be in order. The actual physical determination of area was accomplished in this case by using a dot planimeter. A description of its use is given in Yuill, 1970.

The third method of accuracy reporting used was an analysis of the ground dimensions of the identifiable feature diagnostic of a particular land use type. This method uses a modified concept of ground resolution as a criterion for measuring interpretation accuracy of various remote sensor source data. Quite simply by knowing from previously established training sets what size, i.e. ground dimensions, a feature or structure must be to be recognizable and mappable as a land use category on a given type of imagery one can inject some quantification into the development of land use recognition keys for imagery of different scales and resolving power. No accuracy number or percentage figure per se is given here, but the criterion by which qualitative statements referring to accuracy are made has foundations in distinct numerical form.

The last accuracy method considered here is that of visual assessment. This does not require an elaborate explanation, and suffice it to say that the taking of notes during observations of several data sets can be a useful and in many cases relatively accurate method of analysis. In cases where time is short and a "quick-look" is all that is possible this method certainly has value. The more experienced and knowledgeable an interpreter is vis-a-vis land use mapping and test site characteristics the more accurate will be the assessment.

Interpretation of S-190B Data

The initial analytical step was to interpret photographic enlargements made from the NASA supplied color S-190B frame which covered the Fairfax City and County area. Fairfax City was enlarged to a scale of 1:24,000 and the northeastern Fairfax County was enlarged to a scale of 1:125,000. A Level III land use map was then made from the 1:24,000 photo enlargement and compared to a "ground truth" map of the same area and at the same scale produced from a combination of U-2 photography, topographic maps and field survey. For this example the systematic aligned sample and comparison of area measures by land use category quantification techniques were utilized. There was also some analysis of the minimum identifiable unit size for certain land use features such as housing and industrial structures and transportation features.

A somewhat different method was used in the analysis of the 1:125,000 scale work. Not only was a Skylab generated land use map produced, but an aircraft and an ERTS map as well. The Skylab and aircraft maps used the Level II land use classification whereas the ERTS map used Level I. For comparison purposes, the Level II maps were generalized to Level I and the aircraft map was felt to be of high enough reliability to be considered "ground truth," this assumption being made on a thorough knowledge of the area and on extensive interpretation experience using aircraft data. The statistical tabulations, because of the use of Level I categories, are therefore somewhat generalized, but nevertheless give a measure of how the three sensor systems compare to each other given certain constants.

ANALYSIS RESULTS

Fairfax City Example

The Fairfax City and County area lies in the western metropolitan Washington, D.C. urban-rural fringe. Figure 1 shows the city as it was imaged by the RC-10 camera on a U-2 aircraft and the ETC aboard Skylab. From photographs, enlarged to a scale of 1:24,000, of these same scenes land use maps (Figures 2 and 3) were made using the Anderson classification system, Level III. The map generated from the aircraft data was verified and corrected by field survey and was then considered to be ground truth data. The two maps were then compared using the systematic aligned sample technique mentioned above and the results appear in Table 3.

This sample consisted of 69 points, 57 of which had been classified alike. In this particular case the accuracy of the Skylab generated land use map, at Level III discrimination, was computed to be approximately 83 percent. Of the 17 percent error which remained, nearly 42 percent occurred in cases where the Skylab data were misclassified as unimproved open urban area. This appears to be attributable to the spectral resolution of the color film and spatial resolution of the camera. The colorimetry is such that subtle vegetation differences are imperceptible and there is not enough detail in the data to permit observation of certain residential and commercial structures. Positive identification of these features is, therefore, made even more difficult.

To further analyze the Skylab data of Fairfax City, a comparison of area measurements by land use categories was performed. Areas were tabulated first at Level III (Table 4) and then generalized to Level II (Table 5). The tables indicate a sizeable discrepancy in residential land area. Skylab interpretation had approximately 130 less hectares in residential land than did the aircraft. Nearly all of this difference occurred in the use of single family residential units, which can be attributed to the fact that many single family dwelling units in this area were located in wooded or semi-wooded areas. In this situation the spatial resolution of the sensor was not high enough to detect either houses or other residential "keys," such as street patterns, sidewalks, etc., but the same is true in some cases even with high-altitude aircraft data.

Areas of commercial and services land use were detected quite well by Skylab, especially retail trade areas. This appears to be so because of the distinctive spectral and spatial characteristics of shopping areas. Two main types of commercialized areas are usually found, these being suburban shopping centers and urban commercial strips along major thoroughfares. There was some difference between Skylab and aircraft in the industrial category and this seems mainly to be due to the appearance of some industrial land to be commercial and services on Skylab.

There was a marked similarity between the two systems in the urban-open ground category. Although the spatial discrimination was different between Skylab and aircraft the spectral response to open ground was in many respects similar. Considering the lack of structures, most of which would have been within the ground resolution capabilities of Skylab, the category was not too difficult to delineate.

Forestland interpretation, on the other hand, was less accurate with Skylab. The Skylab generated map had 130 more hectares in forest than did the aircraft, a result attributed to the tree-covered residential area mentioned above.

Northeastern Fairfax County Example

As was done with the Fairfax City example, photographic enlargements were made of the images that covered northeast Fairfax County. This example includes, however, data from ERTS as well. This was done to illustrate how much more comparable Skylab data are to the aircraft data than to ERTS data.

Figures 4, 5, and 6 are land use maps of northeastern Fairfax County at a scale of 1:125,000, generated from aircraft, Skylab, and ERTS data respectively. As aforementioned, the aircraft and Skylab maps were compiled at Level II and the ERTS map at Level I. To facilitate comparison with the ERTS data, the aircraft and Skylab data sets were generalized to Level I (Table 6). The aircraft map was considered as "ground truth" and both Skylab and ERTS compared to it (Tables 7 and 8).

These matrices show that Skylab, at Level I, is accurate to nearly 88 percent. Of the 12 percent error, there was a relatively even distribution in the urban, agricultural, and forestland categories. However, the ERTS data were only accurate to about 65 percent. A good breakdown of the errors made within each Level I category is given in Table 9. For urban and agricultural areas ERTS errors were twice those of Skylab. But for forestland ERTS errors were over four times greater. These higher error figures incurred by ERTS are primarily the result of generalization due to the lower spatial resolution of the Multi-Spectral Scanner (MSS) system. A relative comparison of sensor detection capabilities is given in Table 10.

Further analysis of northeast Fairfax County was undertaken by combining the techniques of determination of minimum identifiable size of a land use element and visual assessment. It is presented in a category by category breakdown as follows.

Urban and Built-up.--Residential land is readily identifiable and delimitable in most cases, the exception being where houses lie under a very heavy forest cover. The data does permit the making of housing quality and/or age statements. For example, older single family residential (SFR) developments as well as newer, more expensive developments are distinguished by areas with substantial tree cover, individual houses appearing as dots, and difficult-to-define roads. The size of some houses appearing as dots is as small as 150 square meters. It should be noted that these structures are visible mainly because of the high contrast ratio between them and the forest. Trying to distinguish between the older homes and the more expensive homes is very difficult.

Newer SFR subdivisions and moderate income SFR housing are easily distinguishable by their street patterns. The actual signature on S-190B data is a combination of reflected light from the streets, roofs, and lawns. Individual houses are not visible. Spectral response in these areas is brighter than in the former areas. The width of these street-house-lawn complexes varies between subdivisions but generally appears to be in the 50 to 90 meter range.

Individual multi-family dwelling units become identifiable as discreet structures when their area exceeds approximately 1,000 square meters and have trees or shrubbery between the buildings. Trailer Parks are distinguishable in low density urban or rural areas. However, they are very difficult to pick out in high density urban areas, except where the park is a large one. Evidence of internal structure within the trailer parks exists but individual trailers are indistinguishable. In a few cases the roads within the court (approximately 5 meters in width) appear to be visible. This particular signature could be the

area between trailers including both the roads and the lawns. A comparison of the appearance of housing types on Aircraft, Skylab, and ERTS data is given in Figure 7.

Areas designated as commercial and services are quite evident in strip development along roads and in complexes. However, delineation of these areas within cities is difficult unless the structure is large enough to differentiate from its surroundings. Although experience and intuition usually permit the mapping of these areas, positive identification of specific commercial activities is nearly impossible. The exceptions to this are some high schools and colleges with adjacent open ground. Individual structures become sharp enough to accurately outline at about the 1,000 square meter size when contrast conditions permit.

Industrial land uses are extremely difficult to differentiate from large commercial buildings. The one type of industrial use that is quite apparent on the S-190B data is tank farms, associated with petroleum refining and storage. Individual tanks with diameters of 40 to 50 meters, spaced only 10 meters apart, are identifiable. Figure 8 compares commercial and industry remotely sensed data.

Transportation, communication and utility uses, because of their linear spatial appearance, are usually easy to identify. The network of transportation routes shows up very well. In some cases, where the contrast ratio is high, the paths followed by light-duty improved roads of 10 meter width are visible. Generally speaking, streets within subdivisions are not visible but their patterns, because of the combination of house and street albedos, are clearly visible. These streets are basically in the 8 to 12 meter width range. The threshold size, above which streets themselves are visible, appears to be between 35 and 45 meters. Large airports are very easy to identify and map. The smaller airports on the other hand, especially those with asphalt single runways less than 4,000 feet in length, are usually difficult, if not impossible, to delineate.

Power line right-of-ways, 50 to 60 meters in width are quite distinctive where they cut through forest tracts. In residential areas and especially in agricultural regions they are far more obscure and usually imperceptible.

The industrial and commercial complex category is, in general, one that is capable of being mapped. It has a bright spectral response and the buildings comprising it are usually large enough to be seen individually. There are some cases where it could be mistaken for an apartment complex though. The point to note here is that the threshold value for positive identification of an individual structure, as such, is approximately 1,000 square meters.

The category of other urban and built-up land consists of such uses as golf courses, driving ranges, zoos, drive-in theatres, some parks, ski areas, cemeteries, waste dumps, sanitary land fills, and undeveloped land within an urban setting. In general, with the possible exception of golf courses and undeveloped land in some cases, it is difficult to decide what activity within this category is occurring. Nevertheless the open land category is identifiable primarily because, by definition, it appears within urban areas. It can, however, be confused with small plots of agricultural land.

Non-Urban Land.--Categories of land use other than "Urban and built-up" are of significance in urban area analysis to the extent that they indicate the regional distribution of phenomena that interact with the city. For example, the land uses in zones of possible urban expansion are significant.

Agricultural Land.--"Cropland and Pasture" is relatively easy to map from the Skylab data, but in some cases is difficult to distinguish from the urban-open category. This is primarily the fault of the film, not the sensor, and it is believed that color infrared film would alleviate this problem for the most part. See Figure 9.

Forest Land.--In most cases using the S-190B color photography forests were mapped as deciduous. The color film did not provide enough spectral differentiation to determine variations in forest type (Figure 9). Here again, as with cropland and pasture, it is believed that color infrared film would provide more spectral differences thereby permitting a more detailed breakdown. In a number of instances the contrast between forest and open land was so low that accurate delineation of the two was difficult. Even so, the data did permit mapping of forest tracts down to the minimum mapping level of 2 x 2 mm (50 x 50 meters on the ground).

Water.--Because of the nature of color film, especially at orbital altitudes, the shoreline delineation of bays and estuaries and identification of lakes and reservoirs, is often difficult. All of these features are within the resolution capability of the sensor and, with the use of color infrared film, could be mapped with near perfect accuracy.

Wetland.--Non-forested wetland areas are generally identifiable. In some areas the actual border between wetland and water or wetland and agricultural land is difficult to demarcate. This too could be eliminated with the use of color infrared film. Forested wetlands are virtually impossible to identify with the Skylab data.

Barren Land.--Strip mines, quarries, and gravel pits are quite visible on the S-190B data but are almost impossible to correctly categorize without supplemental data, such as topographic maps. Transitional areas, however, are not only very evident, but quite identifiable as well, because of a distinctive reddish hue which they exhibit.

Phoenix, Arizona Example

Figures 10, 11 and 12 are examples of Aircraft, Skylab and ERTS images illustrating various land uses in the Phoenix, Arizona area. Note the similarities in land use detectability, despite the differences in physical landscape, with respect to the Fairfax, Virginia data.

CONCLUSION: SUMMARY AND USER BENEFITS

In the interest of greater objectivity, deliberate attempts were made in the body of this report to mute the investigators' excitement at the opportunity of working with such high-quality remote sensor data from space as that of the Skylab S-190B Earth Terrain Camera. The fact is, however, that deriving data of significance for intra-urban land use analysis from previously available data from space--Gemini, Apollo,

and ERTS missions--has been a considerable strain at best. With the S-190B data, however, it is for the first time possible to distinguish and map with considerable confidence such structural urban details as the location and extent of most single-family residential areas, even some residential structures themselves, commercial and industrial areas, individual commercial and industrial structures, streets and roads of moderate size, and considerable detail in the use patterns of surrounding non-urban land. If color infrared film of comparable spatial resolution to that of the color film used in this evaluation had been available, the investigators are confident that even greater detail and reliability of detection of the various land use categories would have been obtained.

The high quality of the Skylab S-190B ETC data dramatizes a change in the experts' estimates of the technological capabilities of space-borne sensors for land use classification and mapping. The USGS Circular 671 classification grew out of the recommendations of the Interagency Steering Committee on Land Use Information and Classification prior to the launch of ERTS-1. The recommendations postulated a Level I categorization most appropriately derivable from satellite sensors; a Level II appropriate to data from high-altitude aircraft; and third and fourth levels requiring low-altitude aircraft and ground data sources. The Skylab S-190B data examined here revealed a capability to distinguish Level III and in some cases Level IV categories in urban area land use analysis. This result reinforces the suggestion that the various hierarchical levels of land use classification henceforth be determined by the requirements of the users and the logic of the classification systems, rather than by the altitude or type of vehicle employed as sensor platform. Clearly, as the example of the Skylab S-190B data illustrates, it is now possible to obtain high-resolution data from space, having considerable value for land use mapping and inventorying in urban areas.

In its capability to resolve ground features critical for land use identification, the S-190B data lies between the capability of the coarser-resolution ERTS multi-spectral scanner and the finer-resolution high-altitude aircraft photography, but much closer to the aircraft photography than to the ERTS. The investigators' experience with users in the Central Atlantic Regional Ecological Test Site (CARETS), the locale of the Skylab photography used in most of this analysis, indicates that data of the caliber of S-190B would find considerable use in the work of planning agencies at the state or regional (e.g. Council of Governments) levels. These users require data of comparable quality and validity to cover areas encompassing several local jurisdictions, so that regional assessments can be maintained for purposes of coordinating plans and providing interface between local jurisdictions and state or federal agency programs. Even some requirements for land use data at local levels--the county or city governmental unit where most of the land use decisions affecting urban areas are still made--can be supplied with data of the quality of S-190B.

Having said the above positive factors concerning the uses of S-190B data, it is necessary to point out that in all cases the data requirements for urban land use planning or management at the decision-making level go beyond the capabilities of the S-190B sensor. Some of the S-190B data can be useful, but all data required by the local users cannot be derived from S-190B. An example may be taken from the data requirements specified by the U.S. Department of Transportation for support of local and regional transportation demand forecasting. One type of data required is a breakdown of residential land use into several density gradations of single-family and multi-family structures. The objective is to obtain an estimate of the location and number of households (dwelling units) as part of further estimates of labor force and trip generation factors. Skylab S-190B data can distinguish some, or most, single-family residential land use areas of recent origin and high enough density and contrast to be separated from adjacent uses of other types. It fails, however, to give a good accounting of multi-family residential uses in most cases. And S-190B cannot provide dwelling unit counts in single-family residential areas, whereas the high-altitude aircraft (U-2) data can. (No remote sensor system is as accurate for estimating dwelling units in multi-family developments as in single-family ones). The question facing the user who must meet all of the Department of Transportation requirements for residential uses is: is it more economical to go part way toward meeting the requirements by using S-190B type data, supplementing it where necessary with higher-resolution photography or ground data sources, or is it more economical to go directly to highest-resolution sources for dwelling unit counts, and derive all necessary aggregations to higher levels (e.g. III, II, and I) from the highest-resolution data?

Since there are demonstrably greater uses of U-2 type data for urban area analysis than data of S-190B resolution, and since the S-190B is so near in resolution capability to the U-2 ability to distinguish dwelling units, it is tempting to recommend that an operational remote sensor system for urban area analysis be pushed to the level of the U-2, rather than remaining at the capability of S-190B. Or, the recommendation might be to combine operational sensor systems of two or more resolution capabilities, to serve users at different levels of the user hierarchy, making sure, however, that the critical high-resolution requirement at the decision-making level is met. The answers to questions of how operational urban user data needs should be met depend no longer upon the results of spaceborne sensor experiments of the Skylab type. The NASA-funded programs of the past several years involving aircraft and satellite sensor tests, culminating now in the Skylab S-190B, have demonstrated amply the technical capability of the sensors. Rather, the remaining questions to be answered are in the areas of developing suitable data delivery systems for users, with a cost-effective mix of manual and automated data extraction methods, and the selection of the cost-effective level of the federal-state-local hierarchy where the data-gathering, interpretation, and analysis capability might best be concentrated. Tradeoffs between possible aircraft and spacecraft platforms are matters of engineering comparisons and tradeoffs. Operational needs for high-resolution data for urban area analysis are urgent, however, and would seem to justify an approach which combines early delivery of some useful data to priority users with a longer-range effort to improve system capabilities and prepare a capability that will most likely be required by users five to ten years in the future.

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TABLE 1. Modified version of the Anderson multi-level land use classification system for use with remote sensor data, used in this study.

LEVEL I	LEVEL II	LEVEL III
1 Urban and Built-Up		
	11 Residential	
		111 Single Family
		112 Multi-Family
	12 Commercial and Services	
		121 Wholesale trade
		122 Retail trade
		123 Business, Professional and personal services
		124 Cultural, entertainment and recreational activities
		125 Educational facilities
		127 Religious facilities
		129 Government, administration, and services
	13 Industrial	
		136 Non-classified industrial
	14 Transportation, Communication and Utilities	
		141 Highways, auto parking, bus terminals, motor freight and other facilities.
		146 Electric, water, gas, sewage disposal, solid waste, and other facilities.
	15 Industrial and Commercial Complexes	
	16 Mixed	
	17 Other	
		171 Improved Open space
		172 Unimproved Open space
2 Agricultural Land		
	21 Cropland and Pasture	
	22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas	
	23 Combined feeding operations	
	24 Other	

TABLE 1 continued.

LEVEL I	LEVEL II	LEVEL III
4 Forest Land		
	41 Deciduous	
		411 Afforesting deciduous
		412 Light crown deciduous
	42 Evergreen	
	43 Mixed	
		431 Afforesting mixed
5 Water		
	51 Streams and Canals	
	52 Lakes	
	53 Reservoirs	
	54 Bays and Estuaries	
	55 Other	
6 Wetland		
	61 Forested	
	62 Non-forested	
7 Barren Land		
	71 Salt Flats	
	72 Beaches and Mudflats	
	73 Sandy areas other than beaches	
	74 Bare Exposed Rock	
	75 Strip Mines, Quarries and Gravel Pits	
	76 Transitional Areas	
	77 Mixed	

TABLE 2. Summary of Data from Remote Sensors Used in this Study for the Fairfax City and County Sample Areas.

PROPERTY	ERTS MSS	SKYLAB S-190B	HIGH-ALTITUDE AIRCRAFT (U-2)
Image Type	False Color Composited Imagery	Color Photography	Color Infrared Photography
Image Acquisition Format	70mm	114.3mm	228.6mm
Acquisition Scale	1:2,910,000	1:970,000	1:130,000
Altitude	915km	435km	21km
Ground Resolution	80m	10m	3.5m
Image Date	06 Oct. 73	05 Aug. 73	27 Oct. 73
Image Time (GMT)	$15^h\ 17^m\ 50^s$	$15^h\ 03^m\ 54^s$	$18^h\ 12^m\ 37^s$

TABLE 3. Matrix listing the number of occurrences of Skylab interpreted land uses in Aircraft interpreted ("Ground Truthed") land uses for the Fairfax City sample. Diagonal is the axis of correct Skylab interpretations. Note categories appear in Table 1.

SKYLAB

AIRCRAFT	111	112	122	125	136	150	171	172	411	412	760
111	34		1					1	2		
112			1								
122			7								
125				1				1			
136					1			1			
150											1
171			1				2				
172	1							3			
411								1	9		
412								1			
760											

TABLE 4. Comparison of Aircraft and Skylab area measurements by Level III land use categories for Fairfax City, Virginia.

	AIRCRAFT	SKYLAB
111	780.4 / 50.21	657.0 / 42.29
112	33.4 / 2.20	25.6 / 1.65
120	6.2 / 0.40	-- / --
121	3.4 / 0.20	-- / --
122	166.3 / 10.70	166.4 / 10.71
123	3.6 / 0.20	1.1 / 0.07
124	0.8 / 0.05	-- / --
125	60.9 / 3.90	99.8 / 6.42
127	2.8 / 0.20	1.7 / 0.11
129	5.1 / 0.30	0.8 / 0.05
136	33.1 / 2.10	22.5 / 1.45
140	0.6 / 0.04	-- / --
141	1.9 / 0.10	7.1 / 0.46
146	-- / --	4.7 / 0.30
150	12.4 / 0.80	4.2 / 0.27
171	55.8 / 3.60	38.1 / 2.45
172	129.0 / 8.30	151.6 / 9.74
411	215.7 / 13.90	339.5 / 21.85
412	5.6 / 0.40	-- / --
431	18.0 / 1.20	-- / --
760	10.0 / 1.20	33.9 / 2.18
	1554.0 / 100.0	1554.0 / 100.0

Note: Area recorded in hectares with associated percent of total area. Example (area in ha./ %of total area).

TABLE 5. Comparison of Aircraft and Skylab area measurements by Level II land use categories for Fairfax City, Virginia.

	AIRCRAFT	SKYLAB
11	813.8 / 52.41	682.6 / 43.96
12	249.1 / 15.95	269.8 / 17.36
13	33.1 / 2.10	22.5 / 1.45
14	2.5 / 0.14	11.8 / 0.76
15	12.4 / 0.80	4.2 / 0.27
17	184.4 / 11.90	189.7 / 12.19
41	221.3 / 14.30	339.5 / 21.85
43	18.0 / 1.20	-- / --
76	19.0 / 1.20	33.9 / 2.18
	1554.0 / 100.0	1554.0 / 100.0

Note: Area recorded in hectares with associated percent of total area. Example (area in ha./ % of total area).

TABLE 6. Comparison of Aircraft, Skylab and ERTS area measurements by Level I land use categories for Northeast Fairfax County.

	AIRCRAFT	SKYLAB	ERTS
1	10,988 / 31.0	11,212 / 32.0	11,312 / 33.0
2	8,992 / 25.0	10,284 / 29.0	9,340 / 27.0
4	15,080 / 43.0	13,488 / 38.0	13,840 / 40.0
5	42 / 0.2	2 / --	-- / --
7	276 / 0.8	268 / 1.0	-- / --

Note: Area recorded in hectares with associated percent of total area. Example (area in ha./ % of total area).

TABLE 7. Matrix listing the number of occurrences of Skylab interpreted Level I land uses in Aircraft interpreted ("Ground Truthed") Level I land uses for Northeast Fairfax County. Diagonal is the axis of correct Skylab interpretations.

	SKYLAB 1	2	4	7
1	64	2	3	-
2	2	53	6	-
4	4	8	79	-
7	2	1	-	1

TABLE 8. Matrix listing the number of occurrences of ERTS interpreted Level I land uses in Aircraft interpreted ("Ground Truthed") Level I land uses for Northeast Fairfax County. Diagonal is the axis of correct ERTS interpretations.

	ERTS 1	2	4	7
1	51	4	14	-
2	3	36	25	-
4	16	15	59	-
7	-	2	-	-

TABLE 9. Percentages falsely assigned to each land use category by Skylab and ERTS.

LAND USE CATEGORIES	SKYLAB	ERTS
1	3.6%	8.4%
2	4.9%	9.3%
4	4.0%	17.3%
7	--	--
$\sum$	12.5%	35.0%

TABLE 10. Relative Comparison of Sensor Detection Capabilities.

LAND USE CATEGORY	ERTS MSS	S-190B	AIRCRAFT (U-2)
Urban and Built-Up	2	1	1
Residential	3	2	1
Commercial and Services	3	2	1
Industrial	4	2	1
Trans.,Comm.,& Utilities	3	2	1
Industrial and Commercial Complexes	4	2	1
Mixed	3	2	1
Agricultural Land	2	1	1
Cropland and Pasture	2	1	1
Forest Land	2	2	1
Deciduous	3	4	2
Evergreen	3	4	2
Mixed	3	4	2
Water	1	2	1
Streams and Canals	1	3	1
Lakes	1	2	1
Reservoirs	1	2	1
Bays and Estuaries	1	1	1
Wetland	2	3	2
Forested	4	4	3
Non-forested	2	2	1

1 - Optimal, 2 - Adequate, 3 - Marginal, 4 - Unattainable

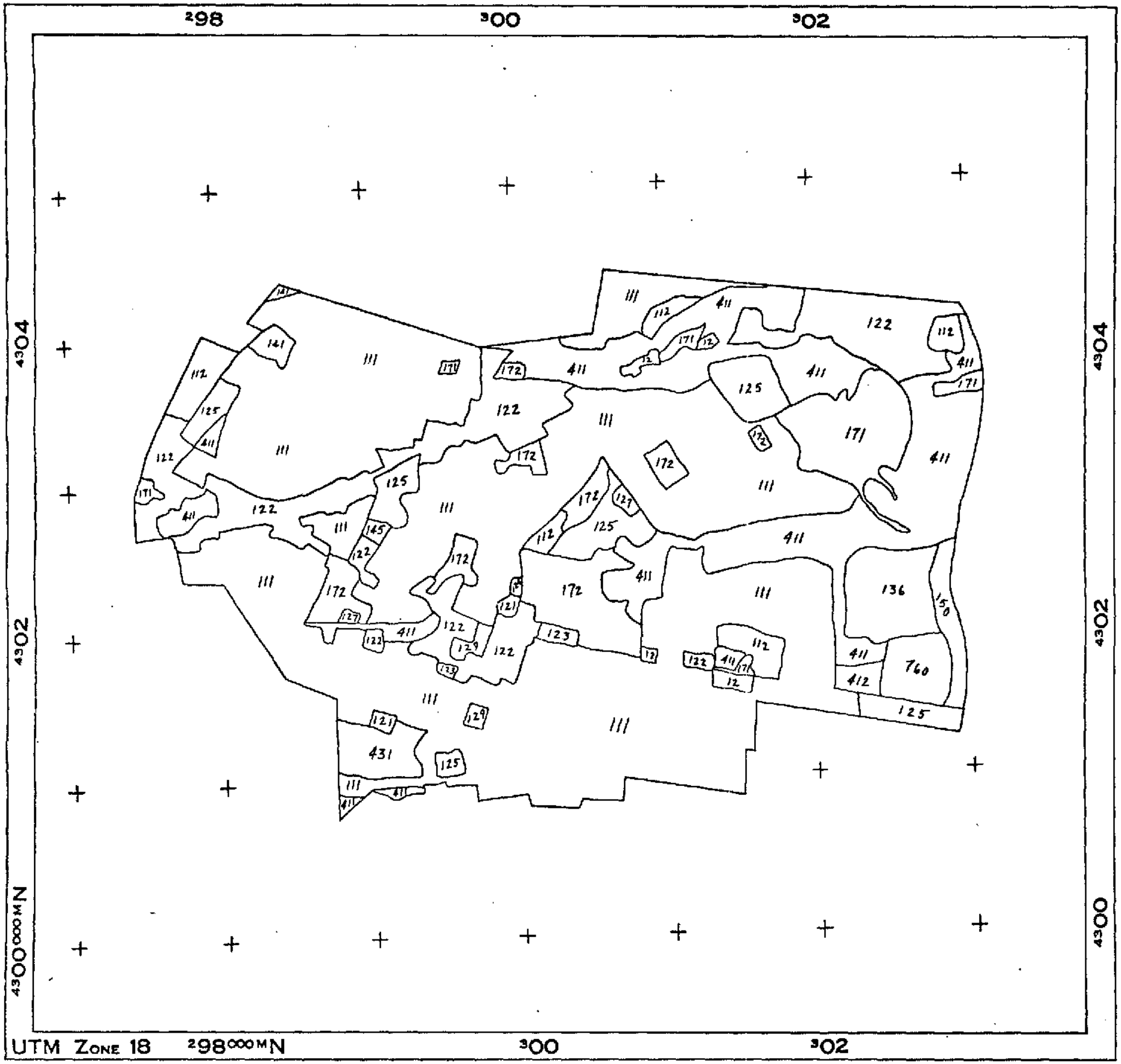
Note: ERTS data was in color composite form, S-190B in color, and Aircraft data in color infrared.

U-2 AIRCRAFT COLOR INFRARED PHOTOGRAPH

SKYLAB S-190B COLOR PHOTOGRAPH

0 1 2 3 Kms.

FIGURE 1. Aircraft and satellite photographs of Fairfax City, Virginia.



AIRCRAFT

LAND USE MAP LEVEL III

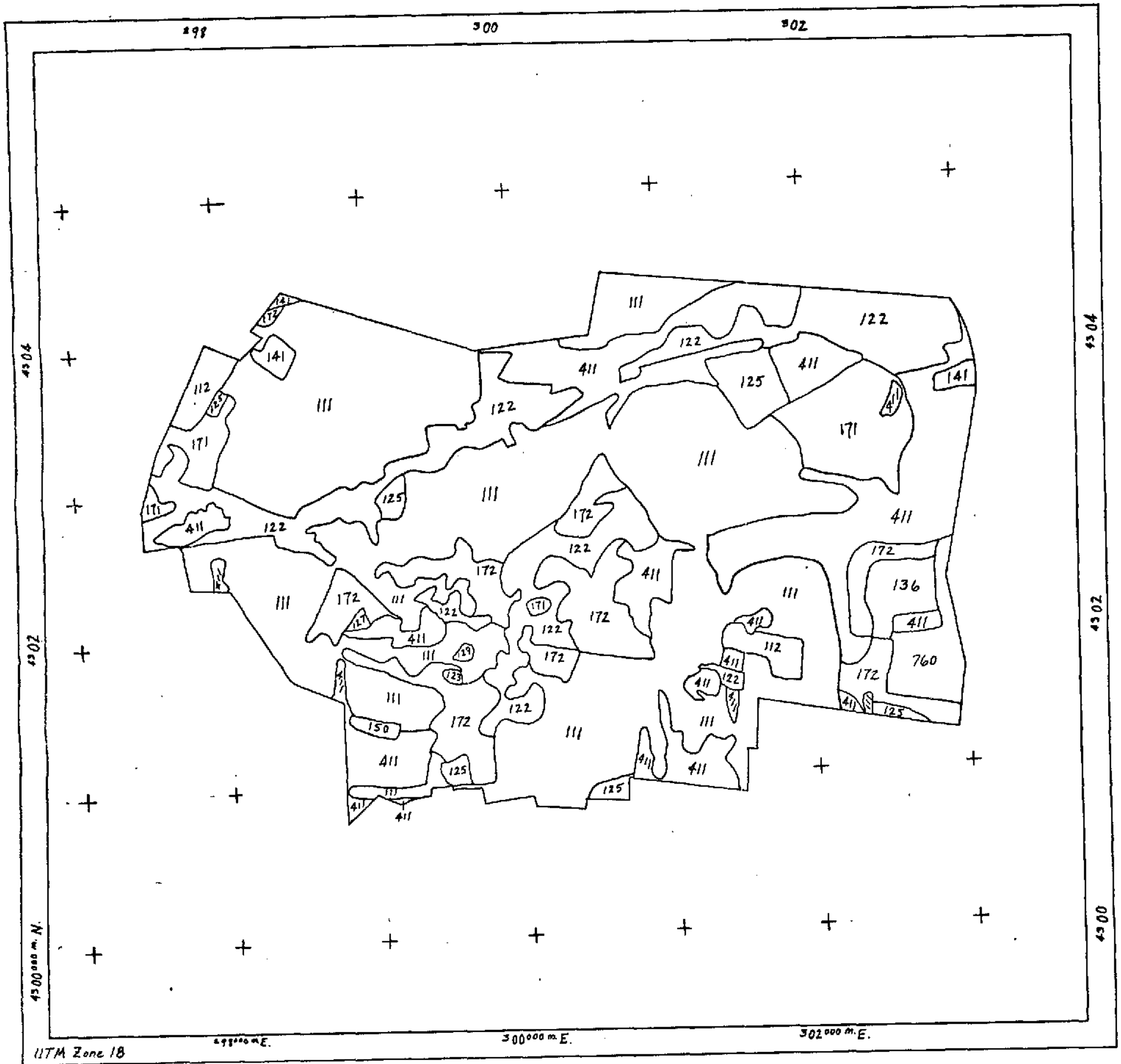
FAIRFAX CITY, VA. 1973

Level III land use categories appear in Table 1.

Land use data compiled from a 1:24,000 scale color infrared photographic enlargement, acquired by the National Aeronautics and Space Administration, Earth Resources Aircraft Project, Flight 73-181, Frame Number 5296, 27 October 1973.

1 0 1 KM

FIGURE 2. LEVEL III LAND USE MAP OF FAIRFAX CITY, GENERATED BY AIRCRAFT DATA.



SKYLAB

LAND USE MAP LEVEL III

FAIRFAX CITY, VA. 1973

Level III land use categories appear in Table 1.

Land use data compiled from a 1:24,000 scale color photographic enlargement, acquired by the National Aeronautics and Space Administration, Skylab Project, Mission 3, Frame Number 83-165, 5 August 1973

1 0 1 KM

FIGURE 3. LEVEL III LAND USE MAP OF FAIRFAX CITY, GENERATED BY SKYLAB DATA.

AIRCRAFT

LAND USE MAP
LEVEL II

AREA WITHIN FAIRFAX CO., VA.

1973

Level II land use categories appear in table 1.

Land use data compiled from 1:125,000 scale color infrared photographs acquired by the National Aeronautics and Space Administration, Earth Resources Aircraft Project, Flight 73-181, 27 October 1973.

5 0 5 10 15 KMS

FIGURE 4. LEVEL II LAND USE MAP OF NE FAIRFAX COUNTY, GENERATED BY AIRCRAFT DATA.

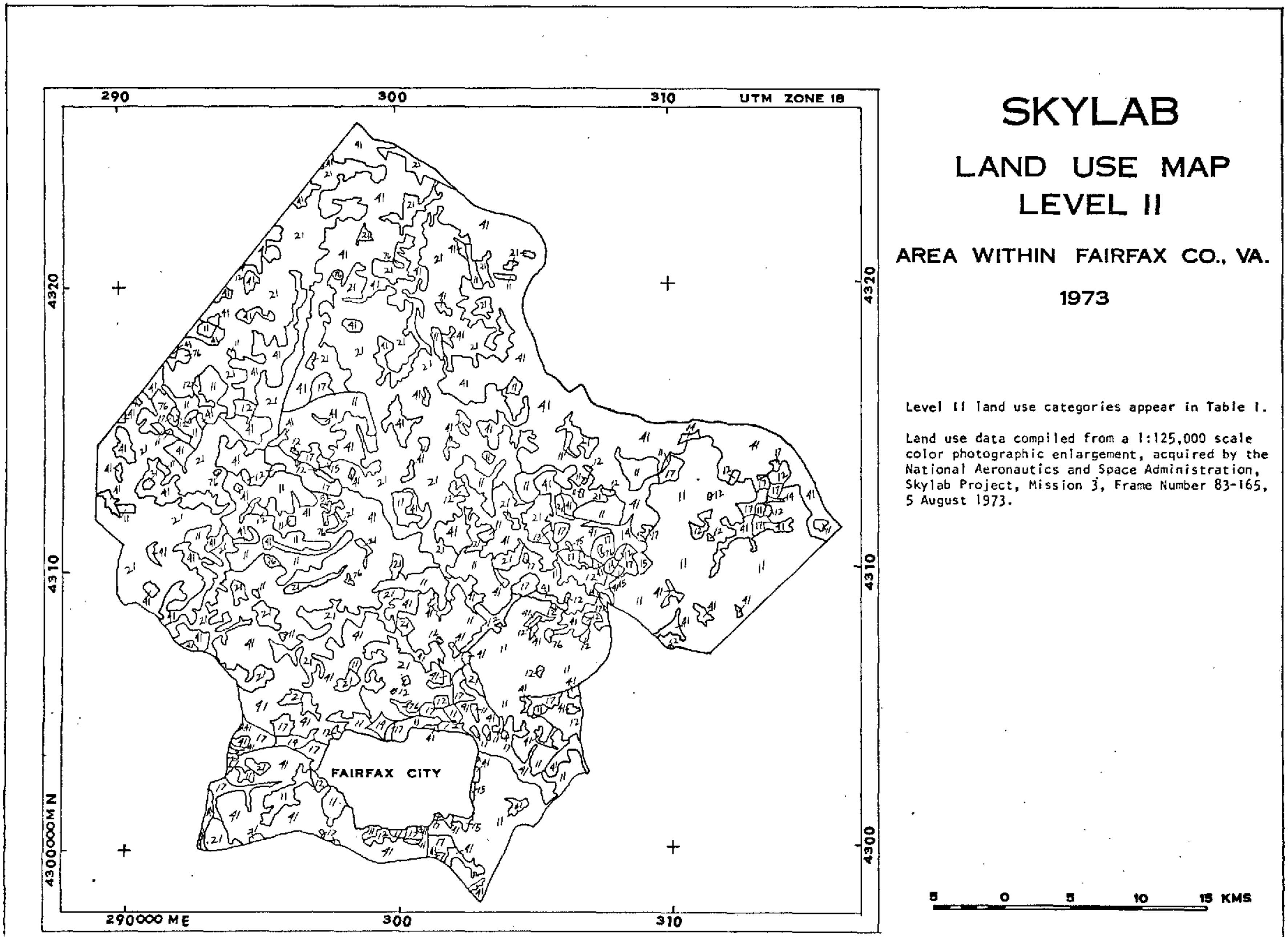


FIGURE 5. LEVEL II LAND USE MAP OF NE FAIRFAX COUNTY, GENERATED BY SKYLAB DATA.

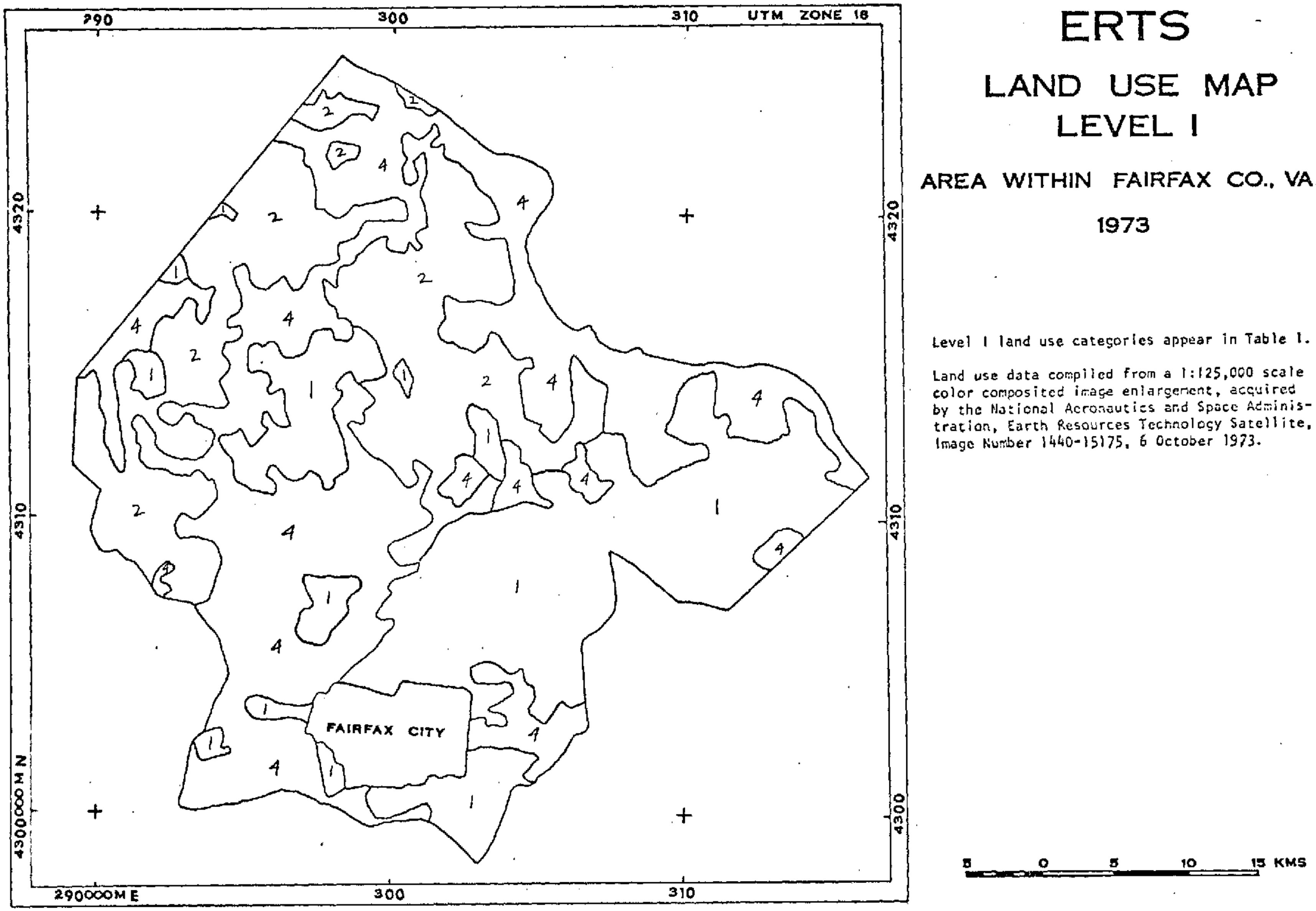


FIGURE 6. LEVEL I LAND USE MAP OF NE FAIRFAX COUNTY, GENERATED BY ERTS DATA.

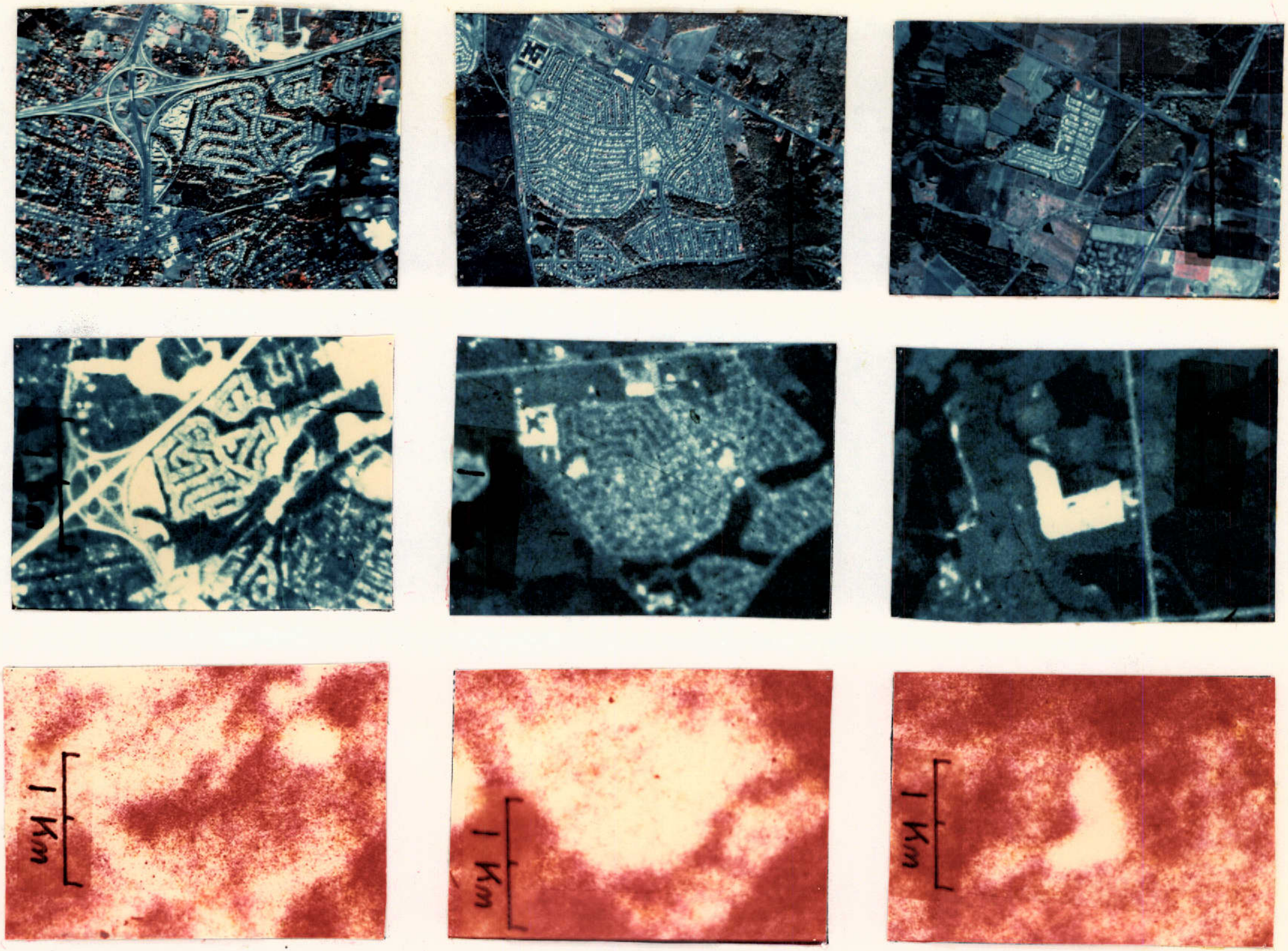
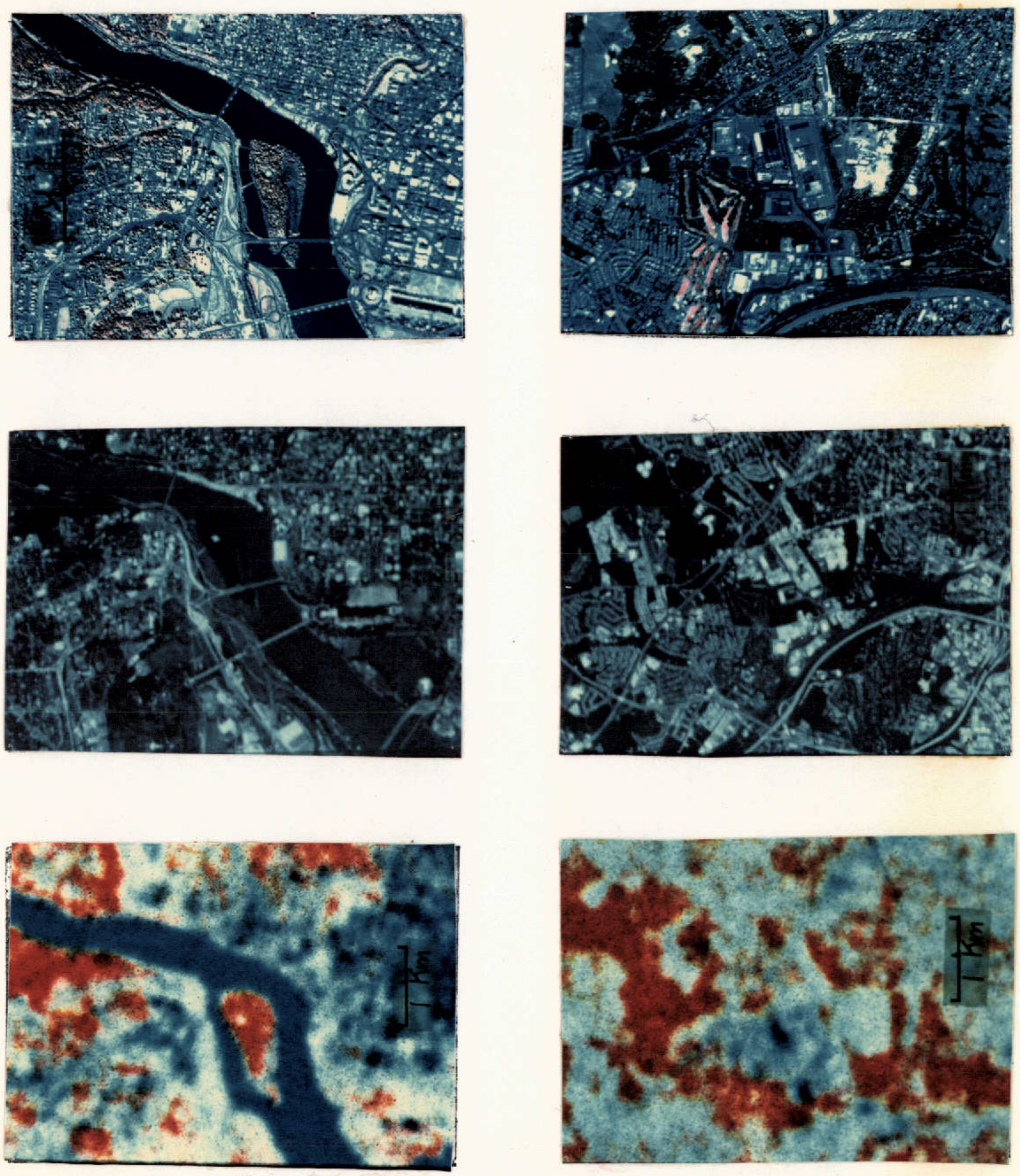


FIGURE 7. Examples of residential types in Fairfax County (western Washington, D.C. suburban area) as imaged from Aircraft, Skylab, and ERTS.

AIRCRAFT

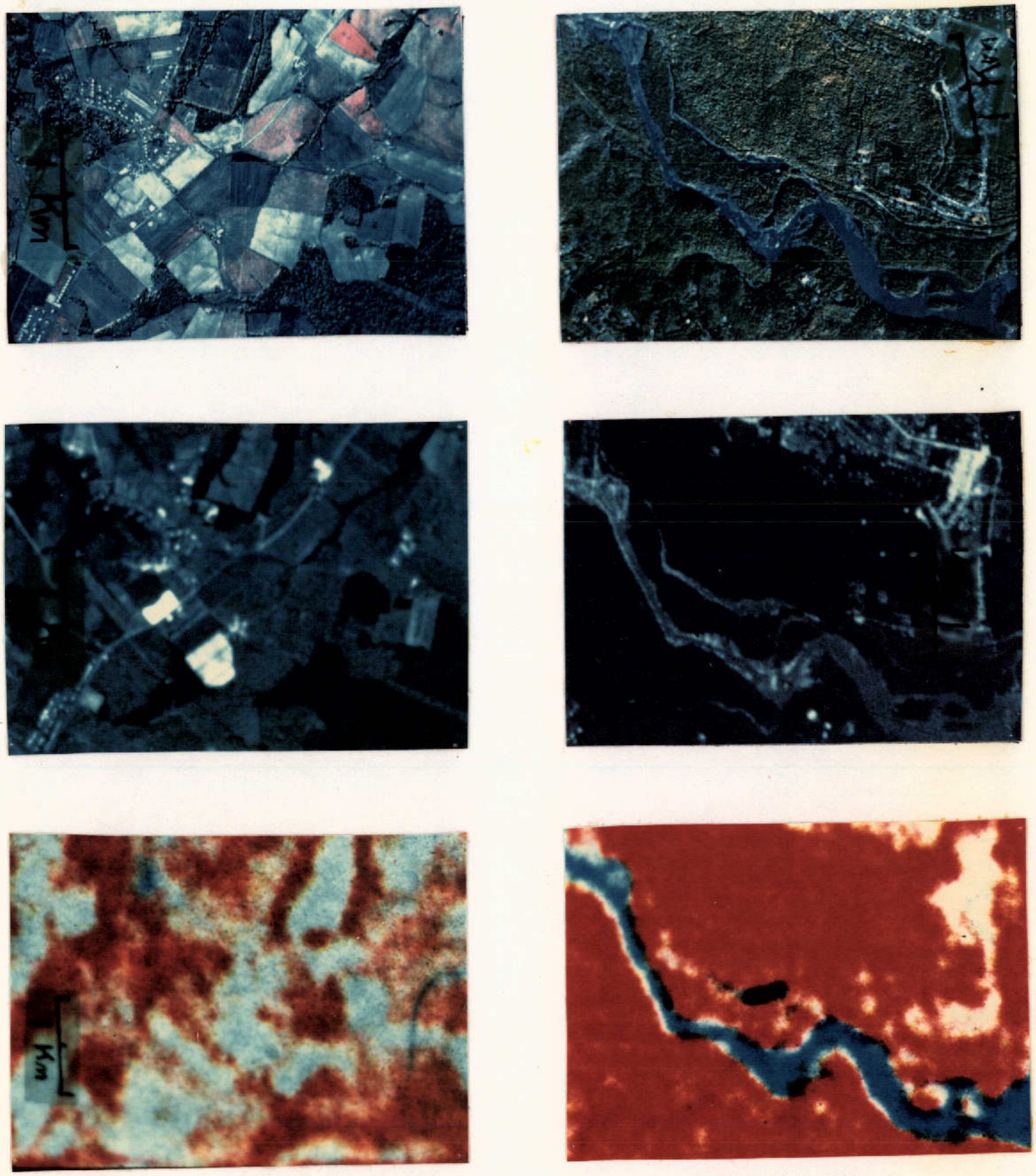
SKYLAB

ERTS



COMMERCIAL   INDUSTRIAL

FIGURE 8. An example of commercial and industrial land uses in the Washington, D.C. metropolitan area as imaged from Aircraft, Skylab, and ERTS.



AIRCRAFT

SKYLAB

ERTS

AGRICULTURAL LAND

FOREST LAND

FIGURE 9. An example of agricultural and forest land uses in Fairfax County, Virginia (west of Washington, D.C.) as imaged from Aircraft, Skylab, and ERTS.

AIRCRAFT

High-altitude aerial photograph of a portion of Sun City residential development northwest of Phoenix, Arizona. This photo was taken on NASA Aircraft Mission 128B, May 1970, by an RC-8 camera at an altitude of 15 kilometers. This photo shows semi-circular golf courses in red. Completed housing development can be seen in the first ring. Construction of new housing can be seen taking place in the second ring to the right and some scraping of land to the north is evident. Two man-made lakes show up well to the southeast of the development.

SKYLAB

Skylab 3 color photograph taken with the S-190B Earth Terrain Camera (ETC) in September 1973. This enlargement shows the same area with the completion of the second ring of development and the filling in of additional housing. The beginning of a new strip of vegetation (irrigated) to the north can be seen.

ERTS

ERTS-1 color infrared composite made using MSS bands 4, 5, and 7 from October 1972 overpass. Resolution degraded, but delineation of vegetation (red) from residential development (blue) can be made.

FIGURE 10. Aircraft, Skylab and ERTS images of Sun City residential development in Phoenix, Arizona.

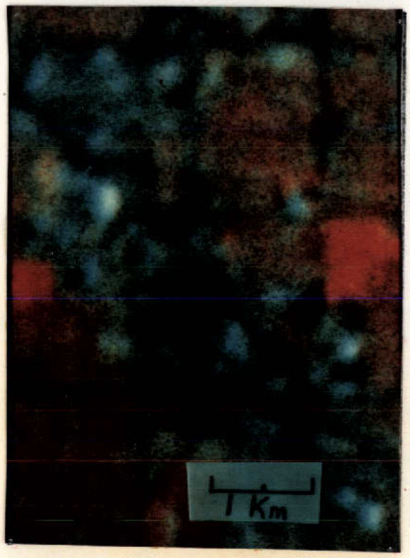
AIRCRAFT

High-altitude aerial photo of a portion of the Phoenix business district. This photo was taken on NASA Mission 128B, May 1970 by an RC-8 camera at an altitude of 15 kilometers. Color infrared photo shows mixed commercial-industrial development running diagonally along Grand Avenue into downtown Phoenix. Most buildings are large, flat roofed structures, many with metallic roofs which exhibit a very bright spectral response.

SKYLAB

Skylab 3 color photograph taken with the S-190B system. This enlargement shows the same area as the aerial photo, however much commercial-industrial land use detail is lost in this color rendition. Only a few of the larger, highly reflective roof surfaces show up distinctly. Even though much detail about commercial-industrial land use cannot be seen on this image, the appearance of this land use type can be clearly distinguished from that of residential land use in Figure 10.

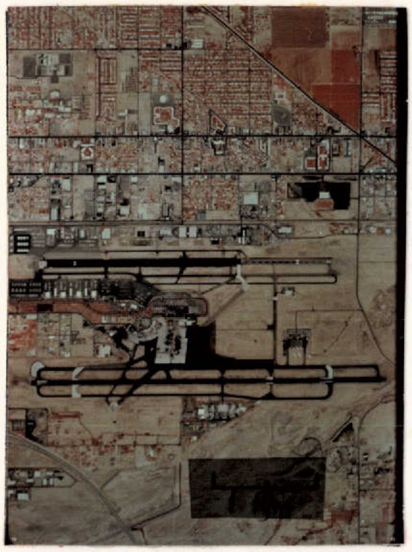
ERTS



ERTS-1 color infrared composite made using MSS bands 4, 5, and 7 from October 1972 overpass. Boundary between commercial-industrial land use (blue) and surrounding area is less easy to delineate with accuracy due to the loss of resolution (fuzziness of land use boundaries occurs). However, one can identify with reasonable assurance the commercial-industrial zone.

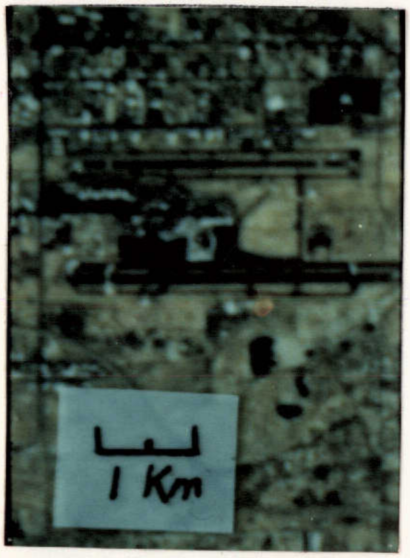
FIGURE 11. Aircraft, Skylab and ERTS images of the Phoenix business district.

AIRCRAFT



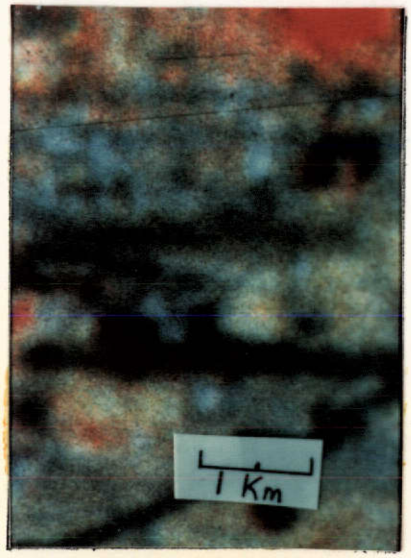
High altitude color infrared aerial photograph taken on NASA Mission 128B, May 1970. Photo shows Sky Harbor -- Phoenix Municipal Airport. Photo offers excellent land use detail, runways, hangars, terminal, etc. and other associated facilities.

SKYLAB



Skylab 3 color photographic enlargement made from the S-190B system. Runways show up clearly and some associated airport facilities can be distinguished.

ERTS



ERTS-1 color infrared composite from the October 1972 overpass. Airport runways can be identified and delineated. Surrounding airport structures however cannot be identified or delineated.

FIGURE 12. Aircraft, Skylab and ERTS images of the Phoenix Municipal Airport.